

BOOK REVIEW

SEISMIC DESIGN METHODOLOGIES FOR THE NEXT GENERATION OF CODES, PETER FAJFAR AND HELMUT KRAWINKLER, editors, A. A. Balkema, Brookfield, Vermont, USA, and Rotterdam, The Netherlands, 1997, 411 pages.

'Everybody talks about it, but nobody does anything about it,' the witticism that refers to the weather, until recently applied equally well to performance-based seismic design, which is the primary subject of this volume of proceedings of a workshop held in Slovenia 24–27 June 1997. Practicing structural engineers have increasingly adopted the philosophy of performance-based seismic design over the last decade, and now they are in search of quantitative methods with which to implement it.

This hardcover book, subtitled 'Proceedings of the International Workshop on Seismic Design Methodologies for the Next Generation of Codes,' contains 36 papers by professors and practicing engineers, along with conclusions developed by the workshop's working groups. Support for the workshop was provided by organizations in Slovenia and the U.S.A. Professors Peter Fajfar, University of Ljubljana, Slovenia, and Helmut Krawinkler, Stanford University, U.S.A., were the co-chairs.

Some of the authors discuss broad aspects such as 'overview of the main issues involved in the development of reliable' performance-based structural engineering code provisions (Vitelmo Bertero, p. 1) and 'the research issues that need to be addressed to make performance-based seismic engineering a process that can be implemented in engineering practice' (Helmut Krawinkler, p. 47). Other papers are at the detailed level of steel frames (F. M. Massolani and V. Piliuso, pp. 241–252), masonry infilled frames (R. Zarnic and S. Gostic, pp. 335–346), or one particular reinforced concrete frame building (J. A. Browning, Y. R. Li, A. Lynn, and J. P. Moehle, pp. 265–276).

Codes in Japan, New Zealand, the United States, Canada, Mexico, Israel, and several countries in Europe are discussed. Short summaries are included of several standard references on performance-based seismic design in the USA, including *Guidelines for the Seismic Rehabilitation of Buildings*, FEMA 273,¹ *Vision 2000*,² *Performance-Based Seismic Engineering of Buildings*, FEMA 283,³ and *Handbook for the Seismic Evaluation of Buildings: A Prestandard*, FEMA 310.⁴ While this raises the critique that some of the papers are derivative rather than wholly

original, the compilation of information makes this book a useful reference work.

The recommendations of the workshop, predictably, constitute a non-controversial, non-prioritized list of good things to do; the more significant value added by this volume lies in its individual papers. This is not to criticize this particular engineering workshop's recommendations but to point out a flaw inherent in the type. Workshops that bring together experts from different topical and geographic areas can help define, in addition to the state-of-art, the state-of-opinion. Naming the opinions of the participants (for example, 'the following consensus statement on Topic X was agreed to by the Workshop participants') is less informative than measuring their opinions ('70% of the academic participants and 40% of the practicing engineers agreed with the statement that ...').

The one truly innovative recommendation in these *Proceedings* calls for deciding upon an international 'set of model buildings, representing the most common styles of construction worldwide...to calibrate new techniques, compare the effectiveness of various codes, and evaluate new design procedures.' (p. iv) In retrospect, the International Decade for Natural Disaster Reduction might have accomplished this task in its first or second year, which would have allowed more research that was relevant from one country to the next to have been conducted in the following years. Chemists around the world refer to the same periodic table, and botanists share the same Linnaean taxonomy, but an engineer in Japan referring to 'woodframe construction' means something different than what is meant by the term in the United States, Germany, or New Zealand.

Most of the papers in this collection focus on the familiar pair of structural engineering concepts, demand and capacity. Krawinkler (p. 54) goes against the grain of conventional wisdom by stating, 'A widely held opinion is that capacity uncertainties are small compared to demand uncertainties. The writer begs to differ; there are many cases in which capacity uncertainties can be comparable to demand uncertainties' especially at the system rather than element level. While Krawinkler and other authors in this volume point out the large amount of uncertainty in estimates of ground motion derived from the work of their earth scientist colleagues, these papers re-focus the burden back on engineers to come up with more accurate and complete ways of estimating how

structures will perform, regardless of how uncertain the design ground motions may still remain.

In that effort to concentrate on the capacity side of the equation, Masayoshi Nakashima ('Uncertainties Associated With Ductility Performance of Steel Building Structures') notes that 'the ductility capacity of structural members is a very important parameter in seismic design, but even after many years of research it is still hardly quantified' (p. 111). He discusses five different deformation limit states that must be considered in quantifying the single concept, ductility, which textbooks treat with apparent ease. Nakashima is joined by several other authors whose research focuses on ductility. E. D. Booth ('International Comparisons of Concrete Element Strength Requirements In Seismic Codes') finds that 'significant differences exist between the strength provisions of the codes studied' (p. 79), and that assumptions embedded in codes and associated design practice make quantitative comparisons difficult. Thus we are faced with the problem that, even if one of these codes were perfectly accurate as an analytical tool and could be set up as an international earthquake engineering 'gold standard,' it would still be impossible to recalibrate the capacities of designs analysed by the procedures in the other codes. E. Cosenza and G. Manfredi ('The Improvement of the Seismic-Resistant Design for Existing and New Structures Using Damage Concept') emphasize the importance of 'the number of inelastic cycles and on the statistical characterization of the distribution of their amplitudes' (p. 119). Maximum ductility demand, they argue, 'does not provide any information about the effective damage potential of the earthquake, that is also related to the low cycle fatigue phenomena' (p. 119). Yugi Ishiyama and Tet-suhiro Asari ('Extreme of Structural Characteristic Factor To Reduce Seismic Forces Due to Energy Absorbing Capacity') reason 'that ductilities are rather vague measures for seismic damage simulations More realistic damage indicators exist, but their application in seismic design processes is complicated and their evaluation strongly time-consuming. Thus inelastic seismic analyses will maintain maximum or cyclic ductilities as damage indicators as a first step ...' (p. 149). H. S. Lew reports on laboratory tests that show that reported ductilities are dependent on the precise loading history (p. 157), and Thomas Paulay ('A Behaviour-based Design Approach To Earthquake-induced Torsion in Ductile Buildings') concludes that 'current code recommendations⁵ do not appear to bear recognisable relevance to conditions associated with the ultimate limit state for ductile systems' (p. 289).

A pair of short but useful papers ('Notes On Definitions of Overstrength Factors') by Peter Fajfar and Thomas Paulay point out that overstrength factors of various names and definitions have been used in several countries since the origination of the concept in New Zealand. While more than one term may be needed, because 'different overstrength factors, clearly defined,

are relevant to different situations' (Paulay, p. 408), these two authors call for greater consistency in the use of terminology. Paulay further explains that the concept is central to 'a comprehensive capacity design philosophy' (p. 408).

Krawinkler notes that performance-based design must predict deformation capacities in the cumulative damage environment of an earthquake, something our current generation of codes has typically avoided.

The argument against an emphasis on cumulative damage modeling is its inherent complexity and the realization that our ability to predict deformation capacities is poor, with or without cumulative damage modeling. So why bother. There are alternatives, such as a rigorous implementation of capacity design coupled with detailing requirements that 'assure' that all elements that are called upon to deform inelastically have a deformation capacity that is 'large enough' even for the most severe seismic event. The argument in favour of this approach is that efforts should be made to *improve* rather than *quantify* deformation capacities (p. 55).

At the very beginning of his paper, 'Research Issues in Performance-Based Seismic Engineering,' Krawinkler brings us up short with a frank assessment of where we stand today: 'Performance-based seismic engineering is a noble concept. Its implementation, however, has a long way to go' (p. 47). The opening of Krawinkler's paper on performance-based engineering has a critical tone to it, but it is clear from the context of the paper and Krawinkler's other work that he comes not to bury performance-based engineering but to praise it:

There are legal and professional barriers, but there are also many questions whether it will be able to deliver its promises. It appears to promise engineered structures whose performance can be quantified and conforms to the owner's desires. If rigorously held to this promise, performance-based engineering will be a losing cause. We all know that we cannot predict all important seismic demands and capacities with confidence in a probabilistic format. There are, nevertheless, compelling reasons to advocate performance-based engineering as a critical area for research and implementation. The objective of seismic engineering should be to design and build better and more economical facilities. Both terms, 'better' and 'more economical', are relative to the status quo. In the writer's opinion, significant improvements beyond the status quo will not be achieved without a new and idealistic target to shoot for. We need to set this target high and strive to come close to its accomplishment. We may never fully reach it, but we will make significant progress if we have a well defined target. Performance-based seismic engineering is the best target available, and we need to focus on it.

Krawinkler's cautionary note is also sounded by several other contributors who are actively involved in major efforts to develop guidelines, standards, and analytical methods, including Chris Poland and Darrick Hom ('Opportunities and Pitfalls of Performance-Based Seismic Engineering') and Vitelmo Bertero ('Performance-based Seismic Engineering: A Critical Review of Proposed Guidelines'). Poland and Hom argue that performance-based seismic design 'has incorporated many new sophisticated tools and techniques. However, what have not changed are the clients,' who need advice from structural engineers 'in a way that they can understand' (p. 75). Poland and Hom are the only authors in this volume who deal with this important issue of who the owner or other final arbiter of design criteria is. In many cases, for example setting mandatory retrofit standards for unreinforced masonry buildings or post-earthquake functionality standards for hospitals, it is society rather than just 'the owner' whose interests are at stake and who has a major voice in setting criteria. They point out that 'For some clients and business owners, these new levels and concepts may be too sophisticated to understand and incorporate into their long-range plans.' In this case, 'it is not feasible to consider performance-based seismic engineering as a useful and visible tool for decision making. It must be incorporated into the general standards for construction as a matter of public policy and applied to all such construction without a clear understanding by the owners' (p. 75).

The next generation of seismic codes and its related standards and guidelines will guide engineers in designing buildings to perform as intended, where 'as intended' means something very specific—according to a scale that includes five different performance levels (e.g. FEMA 273) or as correlated to ten damage states (e.g. Vision 2000 as explained in Poland and Hom, p. 74, or in the ten-level scale proposed for Canadian use by A. Ghorbarah, N. M. Aly and M. El-Attar in 'Performance Level Criteria And Evaluation,' p. 208). In performance-based seismic design, erring on the side of conservatism at either the component or system level is erring nonetheless. Performance-based designers must think like experimentalists, who know that in the laboratory, test results that are better than predicted are fundamentally the same as performance that is less than expected—both outcomes tell us that our theory is a flawed predictive tool.

One of the most familiar formulations of seismic design goals has been for many years the statement included in the SEAOC 'Blue Book' (*SEAOC Recommended Lateral Force Requirements and Commentary*, 1959 and later editions.) Beginning with the 1967 edition, the goal was stated in a way that in today's parlance would be called performance-based. Note that the criteria quoted below⁶ ambitiously include three levels of seismic hazard, each associated with its own structural and non-structural performance levels.

The SEAOC Code is intended to provide criteria to fulfill the purposes of building codes generally. More specifically with regard to earthquakes, structures designed in conformance with the provisions and principles set forth therein should be able to:

1. resist minor earthquakes without damage;
2. resist moderate earthquakes without structural damage, but with some non-structural damage;
3. resist major earthquakes, of the intensity of severity of the strongest experienced in California, without collapse, but with some structural as well as non-structural damage.

The quantitative procedures of the *SEAOC Requirements* (as distinct from the *Commentary*) and the provisions of the Uniform Building Code which have been derived from the *Requirements*, only included one level of ground motion, which was a greatly reduced and simplified design spectrum from the 'the intensity of severity of the strongest experienced in California.' And while the SEAOC criteria imply the ability to predict two structural damage levels and three non-structural damage levels, the *SEAOC Requirements* and UBC provisions have only included one structural and one non-structural performance level in the equivalent static lateral force method used for the design of most structures: the components are designed to remain elastic under the design loading. That load level has been intentionally set low so that elastic analysis methods could be used, with ductile detailing and assumed amounts of overstrength then relied upon with hopeful intent to take up the slack between the artificially low design loads and the levels of forces or deformations that were actually anticipated. Thus we have long had the goal of performance-based seismic design, but as Krawinkler noted, in implementing this goal we have a long way to go.

Most of the attention in this book, as in the performance-based seismic design field at large, is devoted to high performance levels, or levels beyond the life safety rationale of most codes. However, performance-based seismic design is a technical tool that should be equally well suited to defining and reaching lower as well as higher performance levels. Otani ('Development of Performance-based Design Methodology in Japan') reviews damage statistics from the 1995 Hyogoken Nanbu (Kobe) Earthquake and concludes that especially for low-rise buildings, the current Japanese Building Standard Law, as compared to pre-1981 editions of the code, enforced a 'very safe level of performance ... without the choice of the building owner or the structural engineer; i.e., some building owners might have desired to spend less investment on their buildings and might have desired to spend more money for other purposes' (p. 62).

The opening paragraph of this book states in its preface that 'earthquakes in urban areas have demonstrated

that the economic impact of physical damage, loss of function, and business interruption is huge and that damage control must become more a explicit design consideration.' (p. ix) This assumption that we should climb up to the damage control performance level, well above the first rung on the ladder, which is collapse prevention, is inherently attractive to the best minds in earthquake engineering partly because it poses more interesting engineering problems. However, it is a first-world/high-seismic viewpoint. Poorer as well as less seismic regions may find the cost of such protection excessively high in comparison with its benefits.

George Housner has recently stated that 'if the cost of construction is increased by 5 per cent, then 5 per cent fewer structures will be built' (Reference 7, p. iii) which illuminates the cost issue from a different angle and recognizes that society needs to spend its resources on a variety of things, seismic safety being only one item among many on that long list. Collapse prevention has not yet been attained for all buildings across the USA, nor even for all buildings in California, nor universally in New Zealand, Japan, or other developed high-seismic nations with advanced earthquake engineering capabilities. In much of the world, the basic aim of collapse prevention for existing or new buildings is even further from present grasp, and this goal must be sought with very limited resources. Therefore, the challenge of performance-based seismic design for the next generation of seismic codes in many instances will still be set by the old engineering proverb:

Any damn fool can make a building stand up. It takes an engineer to make a building *just* stand up.

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